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PERFORMANCE OF A SEWAGE STABILIZATION POND IN A MARITIME CLIMATE 1957-1958

John N. Wilson, et al

Public Health Service
Portland, Oregon

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by

John N. Wilson, James H. McDermott
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A Cooperative Study of the

U. S. Dept. of Health, Education and Welfare
Washington Pollution Control Commission
Oregon State Sanitary Authority

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PERFORMANCE OF SEWAGE STABILIZATION POND IN A MARITIME CLIMATE

By John N. Wilson, James H. McDermott and Alfred Livingston, III

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Sewage stabilization ponds are rapidly gaining acceptance in this country as a proven means of municipal waste treatment. Histories of the use of stabilization ponds to treat sewage have appeared in several articles; Caldwell (4), Fitzgerald and Rohlich (5) and Parker et al (12). Ponds may be utilized to serve a number of purposes in sewage and waste treatment, but whatever the function, the unique aspect of ponds is the interaction of algae and bacteria - a symbiotic relationship (8) - in which algae by photosynthesis provide oxygen for maintaining aerobic decomposition by bacteria.

Heretofore, most of the performance records of sewage ponds have referred to areas of moderate rainfall, high evaporation and solar radiation as exemplified by Towne et al (15) in studies of ponds in North Dakota. Would they work in the Pacific Northwest with its long rainy season? This was the prime question that stimulated the project about to be described.

The newly constructed sewage stabilization pond at Long Beach, Washington, afforded an excellent opportunity for study of performance

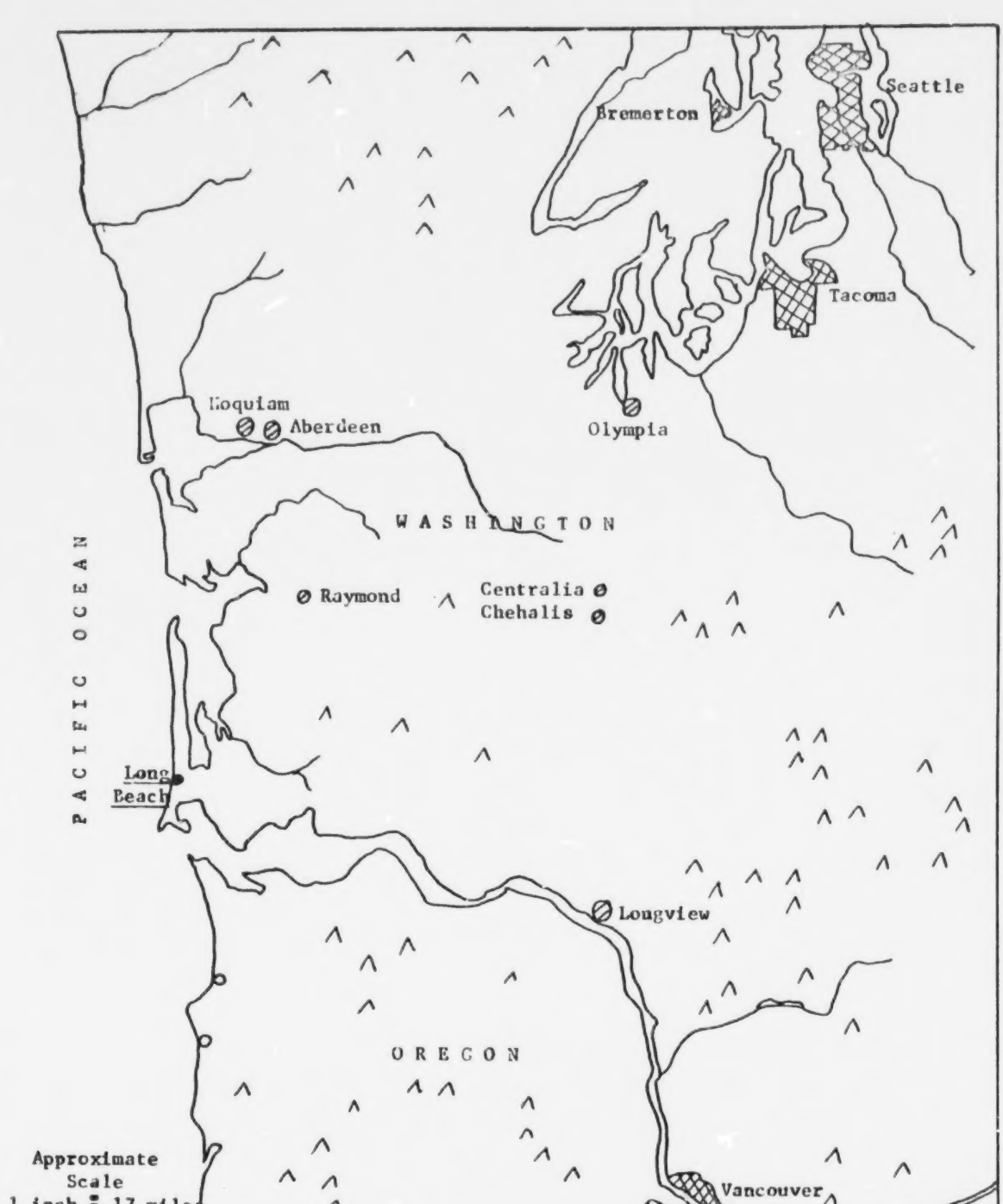


Figure 1
VICINITY MAP OF
LONG BEACH
WASHINGTON

in a maritime climate. There were a number of reasons for this, as will be shown, but among the most important was that it was one of the first to be placed in operation in the area.

Long Beach is situated in the midst of one of the Pacific Northwest's most unique resort areas. The attractiveness of the twenty-mile-long penninsula with its superb sand beach, its cool climate and abundant shellfish resources has caused an influx of thousands of tourists during the summer season (Fig. 1) While the resident population of Long Beach is no more than one thousand, upwards of thirty thousand may be expected over a busy summer weekend.

The mounting problem of sewerage which stemmed from these extremely variable populations was vexing to the city officials for a number of reasons. For years, septic tanks were utilized throughout the town in the belief that by avoiding sewer collection, the problem of an ocean outfall would be obviated. However, the occurrence of numerous septic tank failures with resulting unsanitary conditions in close proximity to the main business district, contamination of the bathing beach on Jacobsen Lake, some one half mile to the North and east from the main business district, allegedly from septic tanks prompted an engineering study in 1955 to seek a remedy. (Fig. 2)

The high estimated cost of the conventional treatment in addition to the prospect of a continuously submerged ocean outfall that could endanger the attractive resort beach discouraged the city planners and temporarily interrupted any further action.

The possibility of a sewage stabilization pond was discussed in the light of successes in other parts of the country. The applicability of stabilization ponds in the coastal area of the Pacific

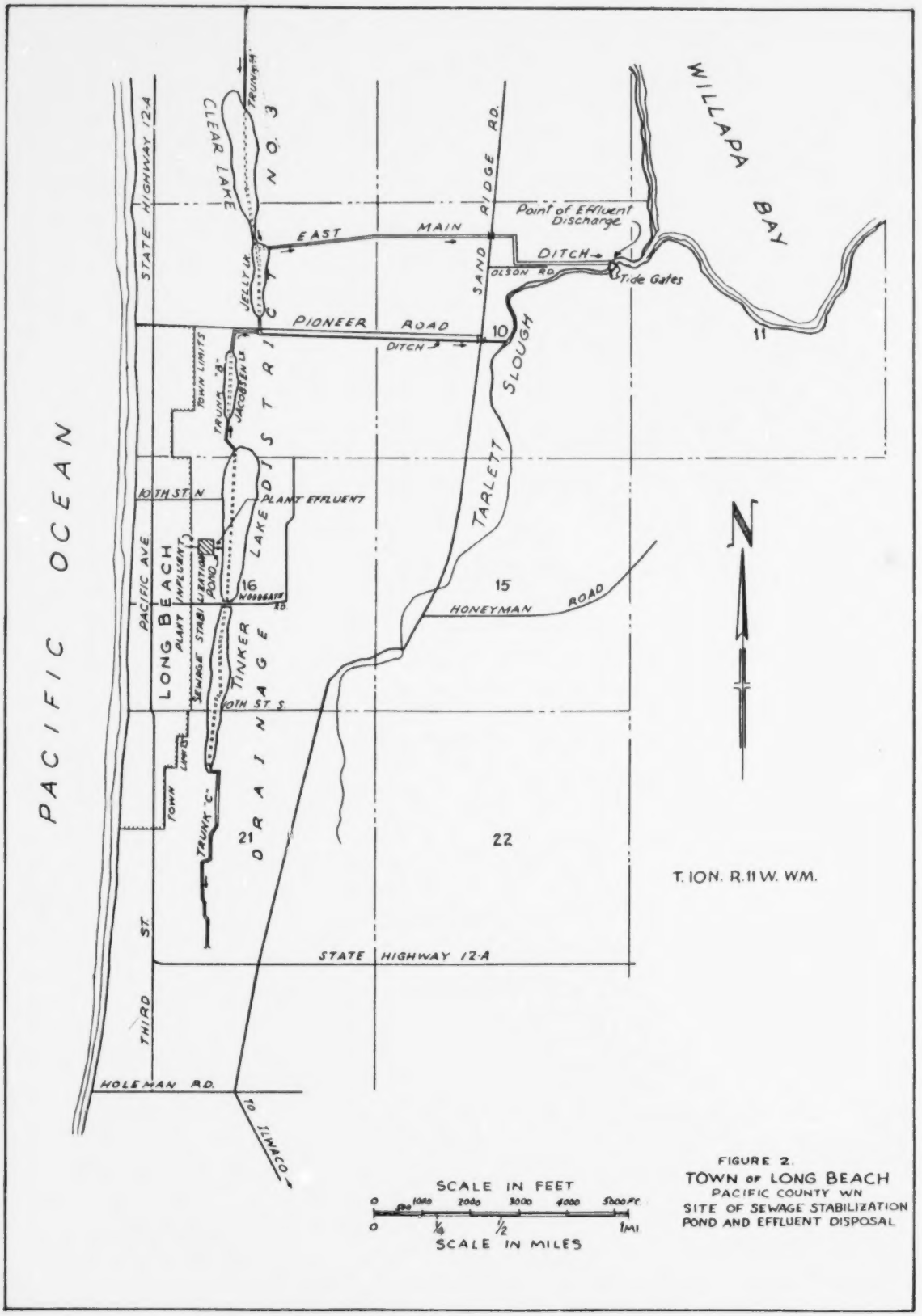


FIGURE 2.
TOWN OF LONG BEACH
PACIFIC COUNTY WN
SITE OF SEWAGE STABILIZATION
POND AND EFFLUENT DISPOSAL

Northwest was questioned by some because of heavy winter rainfall and long periods of overcast skies. However, since most of the heavy loading associated with the tourist population could be expected during the summer season, it was conceded that the plan might be feasible. Other favorable factors such as availability of land, drainage away from the valuable ocean beach, protection of shellfish industry in Willapa Bay, ability to handle variable loads, all rallied strong support for a new sewer system and treatment by sewage stabilization ponds.

In order to assist in the financing of the project, the municipality of Long Beach applied through the Washington Pollution Control Commission for a Federal grant from the Public Health Service. As is required by Federal regulations the Federal officials responsible for reviewing and approving such projects want to be assured that plans and specifications meet with generally-accepted engineering standards as to loading and performance. However, there was no precedent in the Pacific Northwest Coastal regions of high rainfall and low solar radiation. Moreover, information available at the time, 1955, consisted of "rule of thumb" for loading, depth, and pond configuration.

The dearth of knowledge in 1955, coupled with the urgent inquiries and grant applications from other municipalities throughout the area, prompted Federal approval of a construction grant for Long Beach and inception of a joint program of field research to determine the applicability and performance of stabilization ponds in the Pacific Northwest as typified by Long Beach.

State Health and Pollution Control agencies of Washington and Oregon participated in the project with the Portland office of the

Public Health Service. Consultative service and some instrumentation were provided by the Robert A. Taft Sanitary Engineering Center in Cincinnati, which has been sponsoring similar joint research projects on stabilization ponds in the Midwest. Assistance and advice were also forthcoming from Haner and Associates, the engineering firm responsible for construction of the treatment facilities at Long Beach and several other stabilization ponds since that time.

Scope, Methods and Procedures

Field studies were initiated in 1957 and continued through June, 1958. Delays in procuring the flow-measuring device and instruments for measuring solar radiation and light penetration until mid-autumn resulted in more complete records for the Fall-Winter and Spring seasons than for the Summer.

There were eight 24-hour and six 12-hour sample series collected. These were primarily for the purpose of determining BOD loading and efficiency, but at the same time, tests for dissolved oxygen, pH, coliform bacteria and algae were made. Tests were also made from time to time of the effluent ditch and of the receiving waters: Tinker Lake marsh (Fig. 3).

Three series of tests for rate of oxygen production by photosynthesis of the algae were conducted in the secondary cell, the first in December, the second in February and finally in June, 1958. Continuous recording of temperatures was made in the primary and secondary cells. Solar radiation was also recorded continuously beginning November 7, 1957, through the use of a pyrheliograph. Light penetration was measured by using matched photoelectric cells, one of which was submerged; the other was at the top of the dike about five feet above the water surface. Climatological data

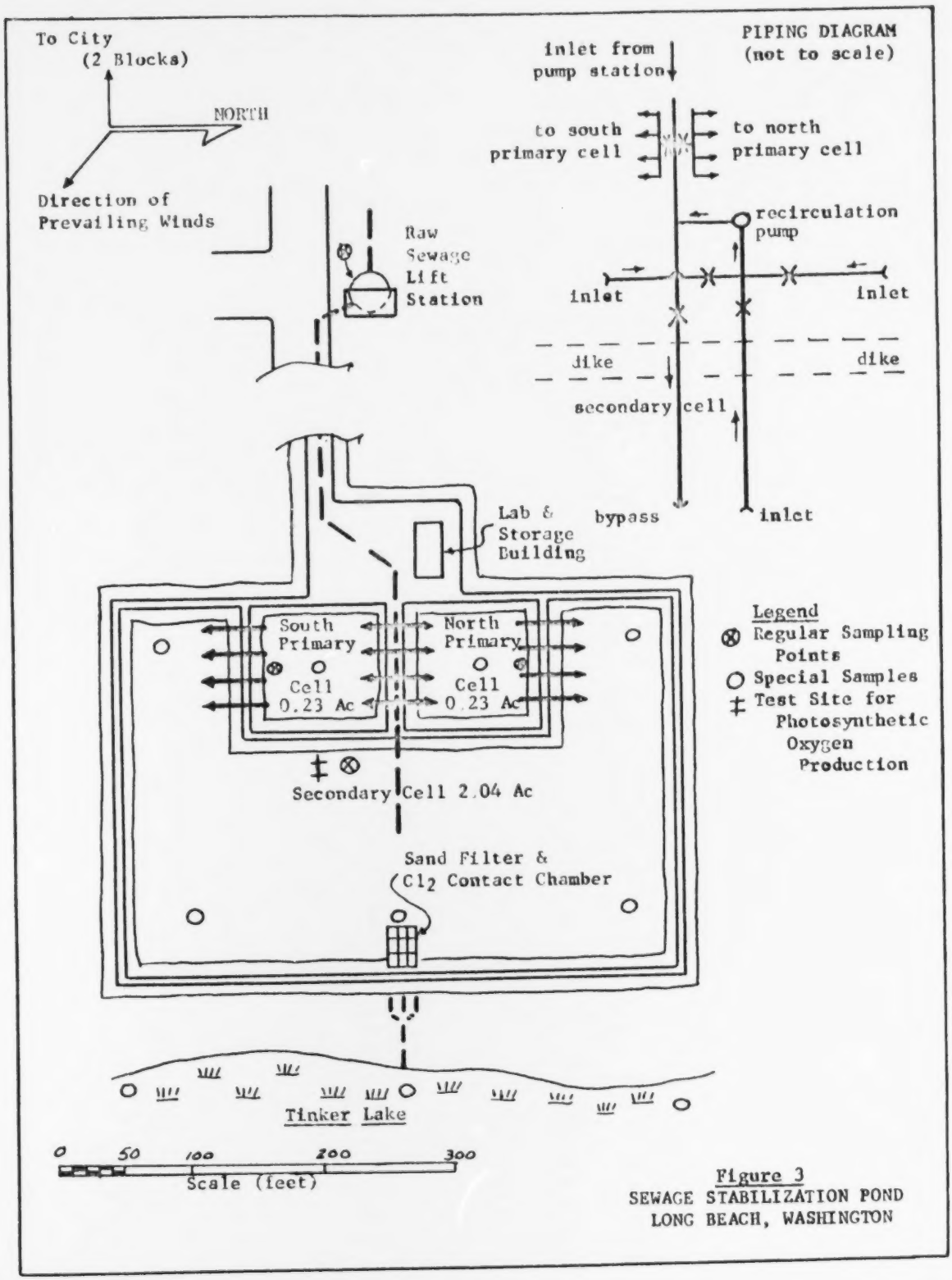


Figure 3
SEWAGE STABILIZATION POND
LONG BEACH, WASHINGTON

were obtained through the Weather Bureau as measured at a station three miles to the north of Long Beach.

Dissolved oxygen samples were collected by the use of tube displacement directly into the sample bottle with the manganous sulfate introduced ahead of time and the remaining reagents added immediately afterwards. The Alsterberg (Azide) modification of the Winkler test was used (APHA, AWWA, FSIWA 1955). The raw sewage samples for analysis of biochemical oxygen demand were composited over twelve 24-hour periods. Grab samples were collected from the primary anaerobic and secondary aerobic cells. The pH was determined by field meter; coliform bacteria by the lactose broth tube method confirmed in brilliant green bile broth.

Plankton algae were identified, when feasible, "on the spot," utilizing the living material. When concentration was necessary, a clinical centrifuge with 50 ml. calibrated tubes was used. The concentrate was counted in a Palmer (10) cell under the medium and high powers of a compound microscope. Straight counts and volumetric standard units were used concurrently.

Tests for nitrogen and phosphorus content were performed according to standard methods. A few core samples were obtained from the bottom of the primary cells. Bottom dredge samples for determination of bottom fauna were collected from all ponds.

A complication in choice of sampling point in the secondary cell arose at the outset because the normal outlet from the underdrains of the unreliable sand filter had an intermittent flow. For extended periods, principally in summer and fall, there was no visible effluent, either at the overflow weirs of the sand filter-chlorine contact chamber or in the filter underdrain line. It was assumed at this time

that evaporation and seepage just compensated for increased volume of inflow at this state of the study.

CLIMATOLOGICAL FEATURES

The Pacific maritime climate of Washington is characterized by wet, mild winters and moist, cool summers. Precipitation in the summer averages about one-fourth of winter precipitation and temperatures are remarkably free from extremes. Table 1 presents data obtained from the weather station located three miles northeast of Long Beach.

Since most of the country's sewage stabilization ponds are located in the Midwest a comparison of climatological data between a central midwestern town and Long Beach, Washington, is in order. Fayette, Missouri, has a sewage stabilization pond which is currently the subject of performance studies by the Public Health Service. Average air temperatures for July, August and September at Fayette for 1957 were 72° F, while at Long Beach, the average over the same period was 59° F. Average winter temperatures at Fayette in 1957 were 30° F; at Long Beach, 54°. Extremes in average monthly air temperatures were from 79.3° F to 23.2° F at Fayette, in comparison to 67.8° F to 52.2° F at Long Beach. Precipitation in the same summer months at Fayette was about 7.5 inches, while Long Beach had 6.3 inches. Precipitation during the winter months of December, January and February, 1957, totalled 5.02 inches at Fayette, and 37.31 inches at Long Beach.

In comparing records of solar radiation from Fayette with Long Beach and other Washington cities, it will be noted that Long Beach in winter (Table II) ranged 40-50% lower than Fayette, but only slightly lower than Spokane. The latter city is in the intermountain area of Eastern Washington, where winters are cold and comparatively dry. Although the pyrheliograph was not available at Long Beach at

TABLE I

CLIMATOLOGICAL DATA - Long Beach, Washington
1957-58
(Station 3 miles NNE, L.B., Wash.)

	TEMPERATURE OF			PRECIPITATION - inches		
MONTH	AVG. MAX.	AVG. MIN.	AVG.	TOTAL	GREATEST DAY	DATE
October	62.1	44.3	53.2	7.46	1.61	23
November	55.8	36.7	46.3	6.62	1.05	11
December	52.2	45.4	48.4	12.92		
January '58	52.4	41.1	46.8	12.10	1.94	14
February	55.8	43.6	49.7	12.29	1.38	8
March	54.2	35.3	44.8	5.71	1.13	31
April	57.9	40.0	49.0	9.36	1.37	15
May	63.1	47.2	55.2	1.54	.47	19
June '58	67.8	54.5	61.2	3.58	1.90	6

TABLE II

SOLAR RADIATION

Month	Mean Langleys per Day*				
	Fayette Missouri	Long Beach Washington	Seattle Washington	Spokane Washington	Seattle-Tacoma Washington
1957					
June	553				
July	550				
August	515				
September	388				
October	286				
November	198	102		109	97
December	161	87	63		66
1958					
January	198	106	78	105	87
February	276	171	139	167	154
March	320	302	362	315	297
April	446	322		438	436
May	552	527	565	626	588
June		447	449	580	572

* A Langley is equivalent to one gram-calorie per square centimeter, for example 553 Langleys/day = 553 gm-cal/cm^2/day

the start of the investigations in summer, 1957, solar records for spring and early summer, 1958, indicated solar radiation not more than 25 per cent lower than Fayette. For example, April in Fayette was 446 Langleys per day; in Long Beach 322; May in Fayette was 552; in Long Beach 527.

Sewage Flows and Records of Performance Based on BOD Loadings

The sewer collection system at Long Beach was constructed as a part of the over-all project in 1955-56. It is a separate system with a minimum of infiltration by ground water. Sewage flows were determined by means of an electric increment timer in the pump circuit correlated with drawdown and pump capacity. The results are presented in Table III.

With the exception of February at 69,300 g.p.d., flows for October through May were less than 65,600 g.p.d. and averaged 51,600 g.p.d., while June through September flows were greater than 65,600 g.p.d. and averaged 81,000. This basic variation, 51,600 g.p.d. versus 81,000 g.p.d., is significant and is attributed to tourists. It should be noted that the June-September average flow was 156% of the October-May average flow. Therefore, the annual mean of 61,400 g.p.d. is not a measure of central tendency, because there are two distinctly different flow and loading patterns. Detention periods, when calculated on the basis of these average flows for the winter and summer seasons, are as follows:

	Average Flow	Detention Period in Days	
		Primaries	Secondary
Winter	51,600 g.p.d.	6	28
Summer	81,000 g.p.d.	4	18

Similarly, it was found that the pounds of BOD influent to the plant based on summer data, 157 lbs./day, was 157% of the winter value of

99.6 lbs./day. Sufficient pond BOD data were collected to establish that seasonal variations also occurred with respect to pond performance. (See Table IV). As indicated in the summary Table V, the primary anaerobic cell loading averaged 291 pounds of BOD per acre-day during the summer tourist season in comparison with an average loading of 239 pounds of BOD per acre-day for the remainder of the year. Under these loadings, the removal efficiencies of the primaries for summer and winter seasons were comparable, 57 per cent and 61 per cent respectively, and although the pond was generally low or devoid of oxygen throughout the year, except at or near the surface, no objectionable odors of sewage origin were encountered.

TABLE III

FLOW DATA - PLANT INFLUENT SEWAGE STABILIZATION POND

Long Beach, Washington

Months 1957 - 1958	Flow in gallons daily		
	Mean	Maximum	Minimum
OCTOBER	39,000	56,600	28,300
NOVEMBER	42,500	61,400	28,300
DECEMBER	42,000	66,000	18,800
JANUARY, 1958	56,800	108,300	37,700
FEBRUARY	69,300	99,100	47,200
MARCH	48,100	75,400	33,100
APRIL	59,000	89,600	42,400
MAY	56,600	117,900	42,400
JUNE	68,000	146,200	51,900
JULY	86,400	147,200	51,900
AUGUST	104,000	136,800	81,300
SEPTEMBER	65,600	136,800	28,300

Annual	Mean	61,400	
	Maximum	147,200	July 6, 1958
	Minimum	18,800	December 9, 1957

TABLE IV

LONG BEACH SEWAGE STABILIZATION POND

B. O. D. LOADING AND REMOVAL EFFICIENCY

Date	Primaries		Secondary		Overall	
	Loading #/A-d	Red. %	Loading #/A-d	Red. %	Loading #/A-d	Red. %
June 2, 1958	302.4	62.0	24.4	18.2	53.7	68.9
June 25, 1958	248.0	70.8	15.4	27.1	47.4	78.7
July 8, 1957	315.4	39.6	40.5	72.8	55.3	84.2
July 9, 1957	315.4	39.6	40.5	72.8	55.3	84.2
July 10, 1957	315.4	39.6	40.5	72.8	55.3	84.2
Sept. 5, 1957	248.3	61.0	20.6	76.1	46.1	90.7
Nov. 7, 1957	255.8	60.4	21.6	51.6	44.8	80.8
Dec. 11, 1958	196.1	68.7	13.0	72.2	34.4	91.3
Dec. 12, 1958	186.8	64.8	14.0	72.3	32.7	90.2
Feb. 5, 1958	340.7	74.6	18.4	84.7	59.7	96.1
Mar. 6, 1958	246.7	57.5	22.3	68.7	43.2	86.7
Mar. 26, 1958	232.1	61.2	19.1	72.0	40.7	89.3
Apr. 15, 1958	220.7	46.0	25.3	60.0	38.7	78.4
May 14, 1958	273.6	46.1	25.6	44.7	39.2	70.4

TABLE V

B.O.D. LOADING AND PERFORMANCE DATA AT LONG BEACH, WASHINGTON

1957 - 1958

	SEASON	
	SUMMER	FALL-WINTER-SPRING
PRIMARY ANAEROBIC POND*		
LOADING, lbs. BOD/acre/day	291	239
EFFICIENCY, %	57	61.2
SECONDARY AEROBIC PONDS**		
LOADING, lbs. BOD/acre/day	30	20
EFFICIENCY, %	57	66
OVERALL		
LOADING, lbs. BOD/acre/day	52	42
EFFICIENCY, %	82	85

* Pond Area - 0.4 Acres

** Total Secondary Pond Area - 2.04 Acres

After a detention time of 4-6 days in the primary cells, the sewage flowed to the secondary cells. During the summer, the BOD load applied to secondary cells average 30 pounds per acre-day while the fall-winter-spring loading averaged 20 pounds. The summer efficiency was 57 per cent in comparison with 66 per cent reduction for the remainder of the year.

The over-all loading on the total surface area of 2.5 acres was 52 pounds per acre-day during the summer versus 42 pounds per acre-day between September and May. The resulting reduction efficiencies averaged 82 and 85 per cent respectively.

These data indicate the versatility of stabilization ponds in the Pacific Northwest. The Long Beach ponds treated sewage effectively from one season of the year to another. Moreover, it should be noted that the over-all efficiencies of BOD removal were comparable to the performance of most conventional treatment plants.

Temperature, Dissolved Oxygen and Nutrients

Temperatures of the raw sewage ranged seasonally from 7° -16.5°, in the primaries from 8° -26° and in the secondary cell from 8°-24.5°. The high reading in the primary of 26° represents surface water at a time of marked thermal stratification.

Dissolved oxygen tests were made at various depths to determine circulation in the secondary cell and the effect of stratification in the primaries. However, the summarized data in Table VI is based upon samples collected consistently at a level of 6-12 inches below the surface.

TABLE VI

VARIATIONS IN DISSOLVED OXYGEN
SEWAGE STABILIZATION POND, LONG BEACH, WASHINGTON

Date	North Primary ppm	South Primary ppm	Secondary ppm
July 8-10/57	0.0-1.4	0.0-1.5	4.2-19.3
Sept. 4-5/57	0.0	0.0	2.5-25.0
Nov. 6-7/57	0.0-3.8	0.0-1.8	6.7-16.0
Dec. 12-13/57	0.0	0.0-0.1	0.1-7.2
Feb. 4-5/58	0.0-0.1	0.0	0.5-1.5
Feb. 21/58	0.0	0.0	
Mar. 6/58	0.0	0.0	11.9-16.6
Mar. 20-21/58	0.6-1.15	0.0	0.1-0.9
Mar. 26/58	0.2-13.8	0.0-12.6	1.4-12.6
Apr. 2/58	1.5-4.35	0.0-0.05	12.1-15.85
Apr. 15/58	0.0-2.7	0.0-1.85	6.4-11.6
Apr. 22/58			6.3-20.
May 14/58	0.5-18	0.0-16.7	0.4-10.3
May 21/58	0.0-4.75	0.0-6.7	
June 2/58	0.0	0.0	0.4-9.3
June 24-25/58	0.0-8.7	0.0-11.85	0.0-14.8

In regard to nutrients, tests for nitrogenous compounds and total phosphorus were run in November, December and February. Nitrites and nitrates were not found. Some reduction - about 50 per cent - was found in the concentrations of orthophosphate during these samplings, but reductions were not in the range to limit the growth of algae. No significant variations in the phosphate concentrations were found during the diurnal cycle.

Efficiency of Coliform Bacterial Reduction

The coliform bacterial densities were somewhat variable as is characteristic of sanitary sewage from a small town. With reference to Table VII, it must be remembered that we are dealing with detention periods of several days in the primaries and from two weeks to a month in the secondary; therefore, direct comparisons of results from raw sewage tests to primary and to secondary for any one series of samples are not so revealing as in the case of a conventional secondary sewage-treatment plant where the time of passage through the entire plant is usually in the order of several hours.

Reductions of coliform bacteria in the primaries, though usually not spectacular, were largely consistent. Where inconsistencies occurred, they may be attributed to short circuiting by means of density currents in hot or cold weather, differences in predator protozoan populations which were noted roughly under a microscope and ultra-violet rays of the sun. The highest over-all percentage reduction was noted in September and December with 99.8 and 99.5 per cent, respectively (See Table VIII).

There is a probable explanation to the inconsistencies of the data for July. For lack of a consistently flowing effluent line, a

Table VII

RESULTS OF COLIFORM BACTERIAL ANALYSES: MPN/100 ml. x 10^3
SEWAGE STABILIZATION POND, LONG BEACH, WASHINGTON

TIME		RAW SEWAGE	PRIMARY CELL	SECONDARY CELL
	7-8-57			
0530		110,000	11,000	150
1100		4,400	360	2,100
1700		46,000	11,000	24,000
2300		46,000	4,600	4,600
	7-9-57			
0500		11,000	11,000	24,000
1100		24,000	4,600	3,400
1700		110,000	24,000	150
2300		4,600	4,600	460
	7-10-57			
0500		11,000	4,600	240
	9-5-57			
1400		110,000	8,800	110
2000		110,000	8,800	210
0600		7,500	8,800	150
	11-6-57			
0900		23,000	7,500	240
1500		15,000	4,600	240
2100		11,000	24,000	460
0300	11-7-57	2,400	24,000	2,400
	12-11-57			
1200		9,300	11,000	240
1800		240,000	24,000	460
2400		46,000	4,600	240
0600	12-12-57	24,000	24,000	240
1200		23,000	43,000	930
1800		23,000	9,300	230
2400		110,000	9,300	230
0600	12-13-57	110,000	46,000	430
	2-4-58			
1200		24,000	24,000	230
1800		4,300	4,300	430
2400		240,000	2,100	150
0600	2-5-58	9,300	4,300	930
	6-25-58			
0700		23,000	5,800	2,100
1400		43,000	2,630	430
1600		43,000	14,200	930

TABLE VIII

EFFICIENCY OF COLIFORM BACTERIAL REDUCTION
AT LONG BEACH

Date	Most Probable Number/100 Ml.x10^3			% Reduction Overall
	Raw	Primary	Secondary	
1957				
July 8-10	40,770	8,420	6,570	82
Sept. 5	75,830	8,800	157	99.8
Nov. 6	12,850	15,030	835	93.5
Dec. 11-13	73,160	21,400	375	99.5
1958				
Feb. 4	69,400	8,675	435	99.3
June 25	36,330	7,540	1,150	97.3

sampling point in the secondary cell was therefore selected, as indicated on the map, at a point far enough removed from the two groups of influent tiles to assure adequate mixing. Unfortunately, this also happened to be in close proximity to the submerged intake for the recirculation pump from which waste may be pumped from the secondary back into the intakes of the primary cells for purposes of freshening the latter. A primary by-pass line also empties into the secondary in the same area. The operator informed the investigators that late in June, prior to the investigation in question, he had not only been running the recirculating pump for a time, but had also by-passed raw sewage directly into the secondary for a short time in order to perform some repairs and maintenance upon the primary influent lines. There was no further recirculation or by-passing until early the following June, 1958.

The effectiveness of chlorination taking place over the sand filters in the so-called contact chamber was problematic. There were heavy accumulations of algae visible in the contact chamber at all times, and it is doubtful that the small quantities of chlorine utilized (1-2 lbs. daily) had any measurable effect upon coliform reduction in the effluent. Samples collected from Tinker Lake at the north and south edges of the pond and from a point in the lake near the confluence of the effluent ditch showed coliform concentrations of 110-5600 MPN/100 ml., as follows:

	Coliforms - MPN/100 ml.	
	Date	
Sampling Station	2/5/58	6/25/58
Tinker Lake, south of outfall	110	4900
Tinker Lake, opposite outfall	2400	5600
Tinker Lake, north of outfall	1500	2400

Because of the extensive, almost uninterrupted growth of emergent, aquatic plants in Tinker Lake and the virtual stagnation of the water, coliform bacteria may not be expected to travel far without being largely dissipated by natural die-off, dilution and sedimentation. Further investigation is needed at this point in the future.

Biological and Related Physico-Chemical Features.

Bottom Fauna and Sludge Characteristics: Two series of bottom samples were collected in 1957 from each of the three cells of the stabilization pond. The primary cells were practically devoid of microscopic life except for an occasional sludge worm. In the secondary cell, the thin layer of ooze over the hard, clay bottom supported a thriving population of midge larvae, Tendipes plumosus, which averaged 1400 or more per square-foot of bottom.

On March 6, 1958, a series of four core samples was collected from each of the primary cells. Deposits of sludge ranged from two to six inches in depth. Results of analysis for total and volatile solids, based upon 500 ml. samples, are averaged as follows:

Source	Total Solids in Grams	Volatile Solids in Grams	Per Cent Volatile Solids
North Primary cell	7.6	1.8	23.5
South Primary cell	11.9	2.1	17.5

The material appeared to be flocculent and easily dispersed and had little odor. In the several weeks preceding the test, there had been little tendency for gas bubbling or scum formation.

Algae: Fifteen series of algal samples were collected at intervals throughout the period of study. About one-half of these

collections were made in conjunction with tests for loading and efficiency of BOD. The remaining collections were made when intervening "spot checks" were conducted to note general characteristics of flow, dissolved oxygen content, possible odors, and the like. Nearly one hundred samples were processed quantitatively and counted in duplicate. The results are presented in Tables IX to XI, and in Figures 4 to 6.

The primary "anaerobic" cells were observed to pass repeatedly back and forth from the anaerobic to quasi-aerobic state. Reference to Table VI indicates anaerobiasis or nearly so in July (stratification), September, December, early March and early June, but aerobic conditions during daylight hours in November, late March, April, May and late June. Recirculation of water with high content of dissolved oxygen from the secondary cell was responsible in part only for the aerobic conditions in late June. The remainder of the aerobiasis in these primary cells is also attributed to a favorable environment for photosynthetic production of oxygen by the algae.

Some algae were always to be found in these primary cells, despite the short detention periods, heavy organic loading, and low-level of light transmission because of suspended sewage solids. In July, 1958, most of the algae in these cells were found concentrated in an upper one-to-three-inch layer of warm water, under which passed density currents of the cold influent sewage.

Predominant algae were Chlorella spp. and Euglena viridis, both of which are known to tolerate a wide range of ecological conditions and to photosynthesize at low levels of solar radiation.

The secondary aerobic cell had a bloom of algae from early summer to late fall that was distinctly different from any of the blooms that developed in the primary cells. The two responsible

TABLE IX

LONG BEACH SEWAGE STABILIZATION POND

ALGAE IN NORTH PRIMARY CELL

Month 1957-58	Standing Crop No/ml.x10^4	Volume of Algae in P. P. M.						
		Chlorella spp.	Chlamydomonas sp.	Micractinium pusillum	Euglena Viridis	Scenedesmus sp.	Other	Total
SEPTEMBER	44	16.2	15.3			3.8	74.9*	110
DECEMBER	3.2	1.7			11.0	1.6	3.2	17.5
FEBRUARY	3.5	2.5			27.7			30.2
MARCH	13.9	6.9	.8		115.9			123.6
APRIL	10.5	6.9			93.2	.008	1.4	101.5
MAY	68	59.1	3.65		87.7		181.8**	332.3
JUNE	67.6	46.7	4.6	32.8	16.2	7.23		107.5

* Navicula spp.

** Euglena sp. (Smaller than E. viridis)

TABLE X

LONG BEACH SEWAGE STABILIZATION POND

ALGAE IN SOUTH PRIMARY CELL

Month 1957-58	Standing Crop No/ml.x10^4	Volume of Algae in P. P. M					
		Chlorella spp.	Chlamydomonas sp.	Euglena viridis	Scenedesmus sp.	Micractinium pusillum	Total
SEPTEMBER	39.1		52	6.5	3.7		61.2
DECEMBER	1.1	.8		4.7			5.5
FEBRUARY	2.5	85.8		24.5			110.3
MARCH	6.6	1.79		116.7	.09		118.58
APRIL	5.5	4.64		24.9			29.54
MAY	34.6	20.74	3.52	35.1	1.29		60.65
JUNE	43	29.09	2.08	61.8	8.6	26	127.57

TABLE XI

LONG BEACH SEWAGE STABILIZATION POND

ALGAE IN SECONDARY CELL

Month 1957-58	Standing Crop No/ml.x10^4	Volume of Algae in P. P. M.					
		Micractinium pusillum	Scenedesmus sp.	Euglena viridis	Chlorella spp.	Other	Total
SEPTEMBER	11.9	165	144				309
NOVEMBER	6.2	283	9			3	295
DECEMBER	3	72	11	8.9	.8		93
FEBRUARY	.37		4.05	2.48	.29		6.8
MARCH	7.5		5.1	62	3.9	.27	71.3
APRIL	20.6		8.9	6.1	14		29
MAY	15.8	21.7	3.6	5.1	14.2	.6	44.6
JUNE	3.5	66.1	22.5	4.8	.92	2.88	97.2

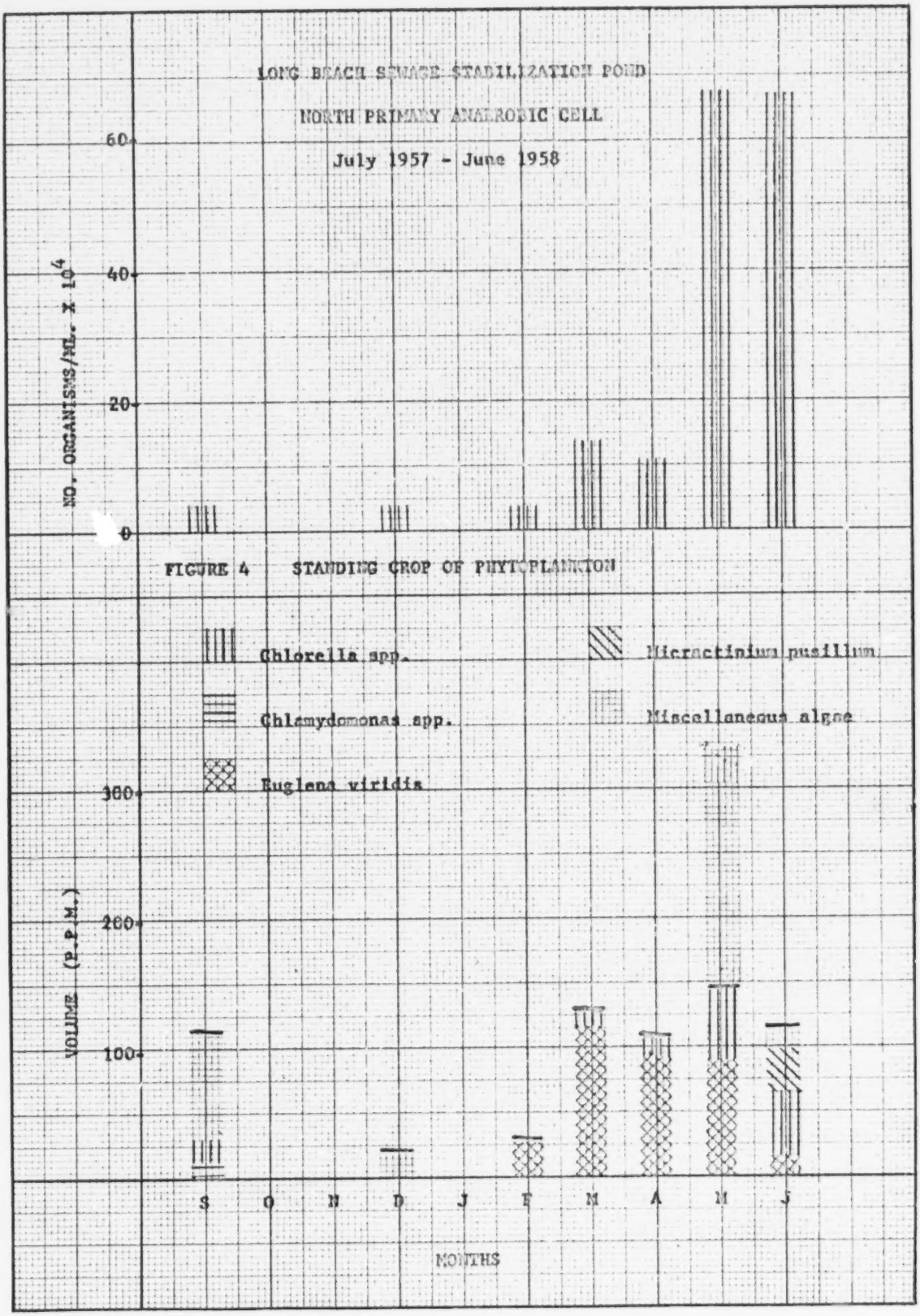


FIGURE 4 STANDING CROP OF PHYTOPLANKTON

Form No. 899—20 Squares to Inch

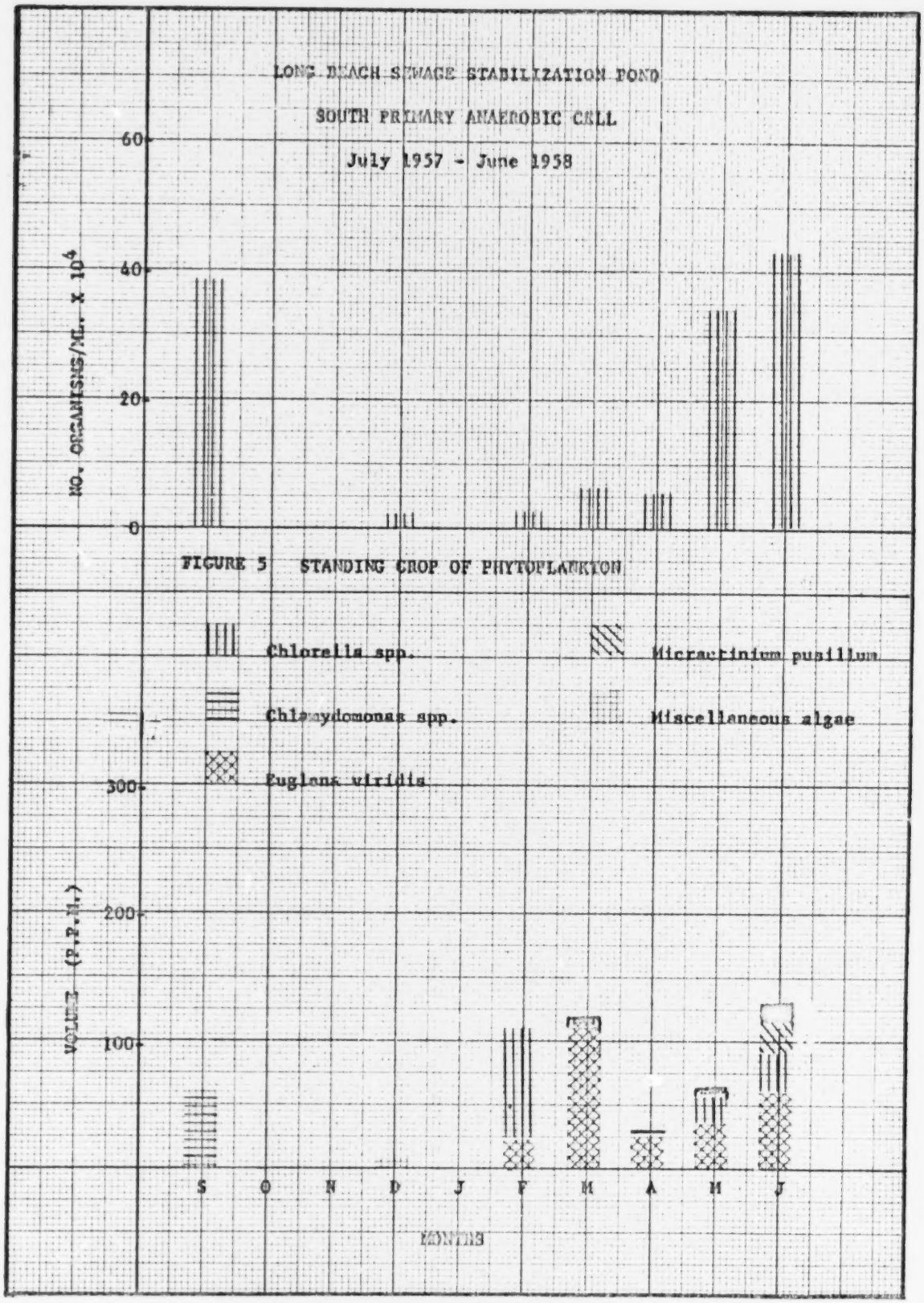


FIGURE 5 STANDING CROP OF PHYTOPLANKTON

Form No. 899—20 Squares to Inch

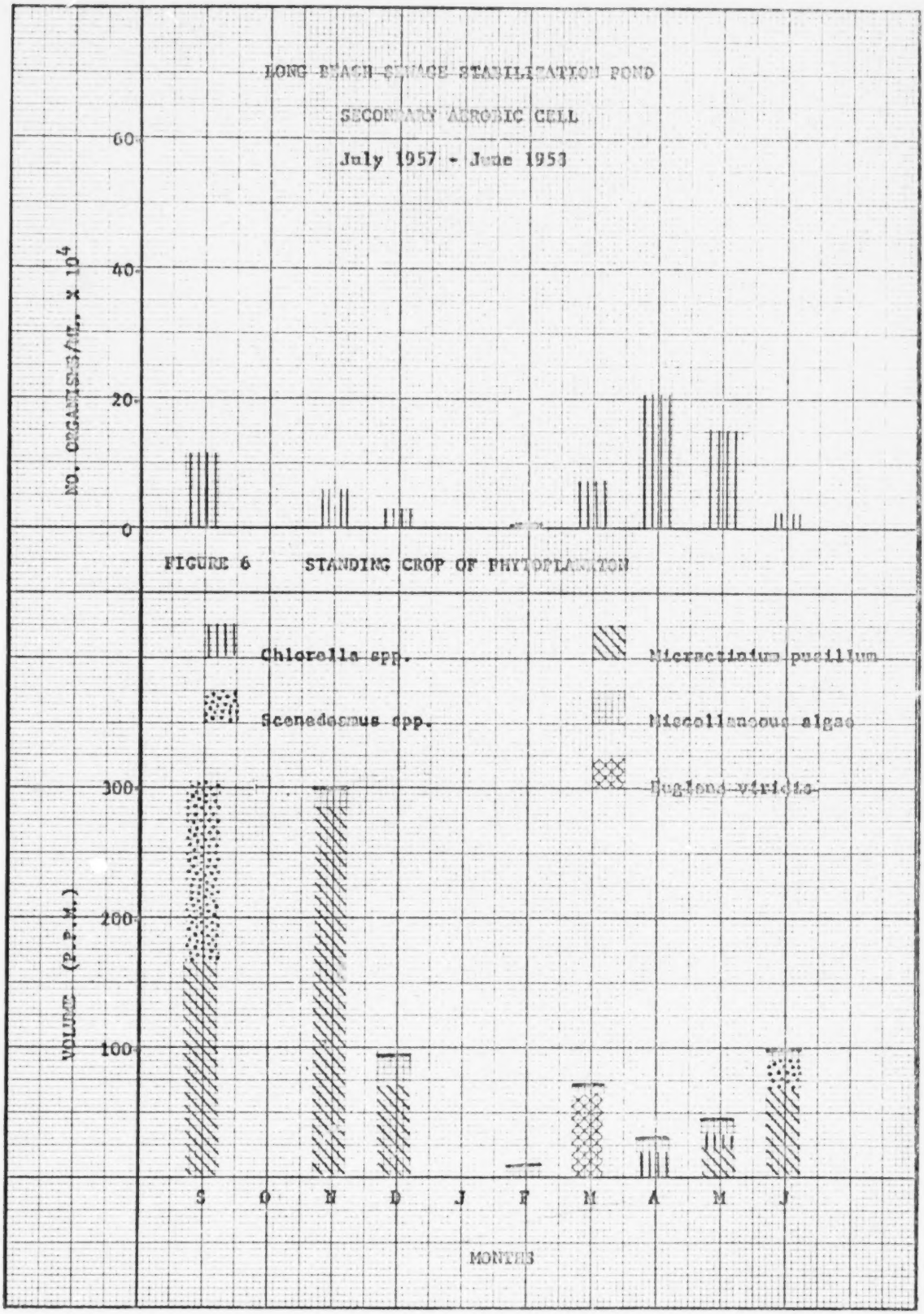


FIGURE 6 STANDING CROP OF PHYTOPLANKTON

Form No. 899—20 Squares to Inch

organisms were green algae of the species Micractinium pusillum and Scenedesmus quadricauda. Highest concentrations were found in September, when 309 ppm occurred. Expressed numerically, the standing crop of those organisms was 11.9×10^4 per milliliter.

A contrasting phase of algal development in the secondary cell occurred in winter and spring. Populations of algae changed radically in composition with total disappearance of Micractinium pusillum and greatly decreased numbers of Scenedesmus spp. These algae were replaced in the secondary cell by algae carried over with the overflow from the primary cells: Euglena spp., Chlorella spp. and Chlamydomonas spp.

But this replacement of flora in the secondary cell was punctuated by two distinct cycles at six-week intervals of population shifts from predominance of plants to predominance of animals and vice versa. On February 4th, there was a large population of water fleas, Daphnia longispina, which had apparently grazed the algae almost to the point of disappearance. As a result, dissolved oxygen had dropped to a diurnal range of 0.5-1.5 ppm (Table VI). The following day the water fleas were decreasing in number, having exhausted their food supply. Within a week the algae - mostly Euglena viridis - returned in good numbers and the range of O_2 increased accordingly.

Another similar cycle was observed March 19-20. Again, recovery was rapid, but this time with Chlorella spp., the predominant algae. Some Micractinium pusillum and Scenedesmus spp. also reappeared, for the first time since December. The nearly doubled solar radiation in March, 302 L/day, over February, 171 L/day, was probably responsible for encouraging the reappearance of these algae,

which are normally characteristic of summer and fall.

Owing to the favorable light conditions and lightened loading on the north primary cell at the time of the latter (March) invasion of Daphnia in the secondary cell, an algal bloom of Euglena viridis occurred in this primary cell. It functioned for a time as a true aerobic cell with D.O.'s ranging from 0.0-8 ppm. and with BOD reductions to correspond, both functions being carried on at a higher level than in the secondary cell at that time.

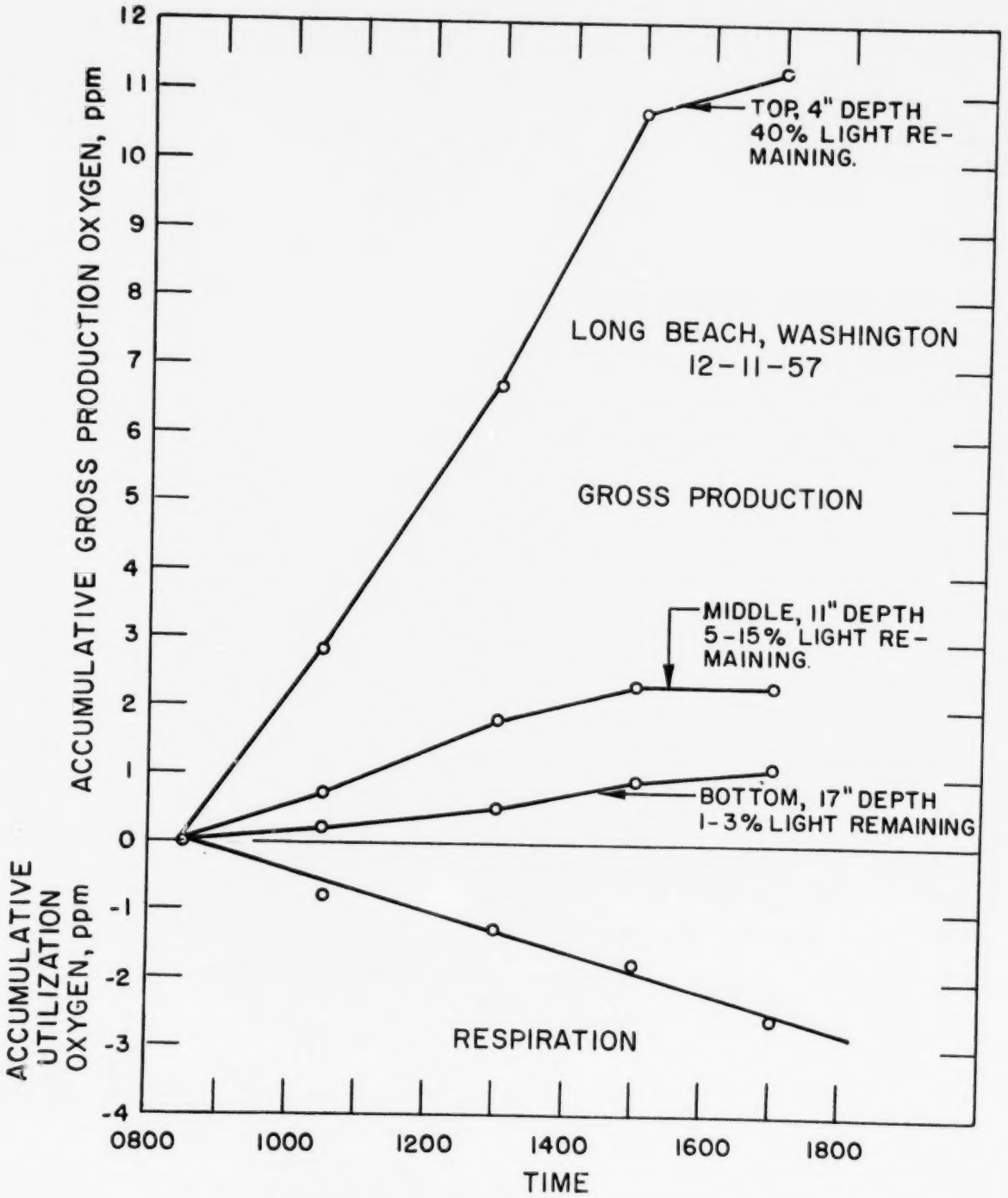
Rate of Oxygen Production by Photosynthesis: To perform this test, BOD bottles were filled with water from the secondary cell, sealed without entraining air and placed in pairs upon shelves located at three depths and allowed to incubate for two hours underwater in the same water from which the samples were drawn. One bottle of each pair was wrapped with aluminum foil to exclude the light; the other was left unwrapped to allow light to act upon the algae contained within. Dissolved oxygen determinations were made at the beginning and end of each of four incubation periods through the day. Light penetration was measured with matched photo-electric cells at the beginning and end of each incubation period throughout the day.

The loss of dissolved oxygen in the dark bottle represents the amount used by the algae for respiration plus an amount to satisfy the BOD; the gain in oxygen in the light bottle represents the net O_2 production less that amount used for plant respiration and BOD satisfaction.

A single day's run - December 11, 1957 - has been selected for discussion because the results demonstrate dissolved oxygen conditions under the kind of adverse conditions of light and rainfall that are typical of a North Pacific maritime climate. During this month of minimum solar radiation, about 87 Langleys per day, oxygen was being produced. It was a rainy day with a 10-mile-per-hour breeze blowing from the south. The high point on the pyrheliograph all day was 0.65 gm. cal./sq/cm./day. Water temperature was 9.0° C. Dissolved oxygen in the secondary cell ranged from 3.1 ppm at the beginning of the test to 6.6 ppm at 6:00 P.M. (1800). Content of algae had been rapidly decreasing over the previous month, from 295 ppm on November 6th to 93 ppm on the date of the test. Micractinium pusillum was still predominant with 72 ppm. and Scenedesmus spp., Euglena viridis and Chlorella spp. also present in that numerical order. Total numbers of algae per ml. was 3×10^4 in comparison to 6.2×10^4 on November 6th.

Figure 7 indicates that oxygen was produced from the top of the pond (4-inch depth with 40 per cent or more of the surface light remaining) to the pond bottom (17-inch depth with 1-3 per cent of the light remaining) throughout the test period from 0830 to 1700. During the 8.5 hour test period, gross oxygen production at the top, middle and bottom were respectively: 11.3 ppm, 2.3 ppm and 1.1 ppm. While this production was occurring, the oxygen demanded by the algae and bacteria amounted to 2.6 ppm which is equivalent to a rate of 0.306 mg. O_2/liter per hour or 7.3 mg. O_2/L for an entire 24 hour period.

These light-dark bottle tests showed that production of oxygen in excess of respiration existed only in the uppermost 12



ACCUMULATIVE GROSS OXYGEN PRODUCTION AND UTILIZATION

FIGURE 7

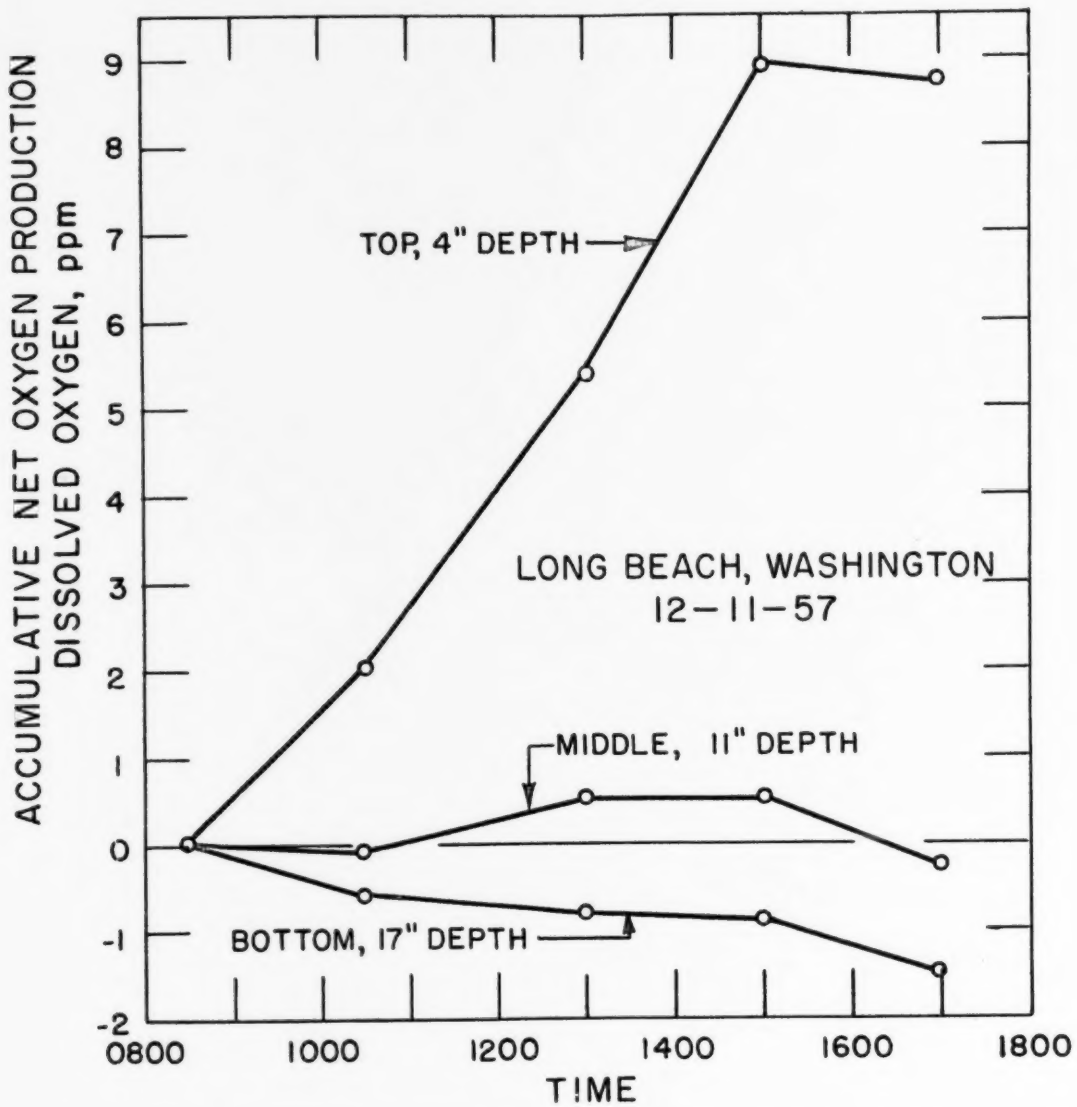
inches on this day of low light intensity (Figure 8). Moreover, this excess was apparent only for the brief period from 1100 to 1600 when solar radiation was maximal.

When the results of the 24-hour sampling series for December 11-12, 1957, were compared with the foregoing, the dissolved oxygen in the secondary cell was found to be maintained throughout the night. Furthermore, there was no evidence that stratification occurred because the D.O. readings were nearly the same ($\pm$ 0.5ppm) from surface to bottom of the secondary.

Clearly, the light-dark bottle test did not give a true indication of the regimen of photosynthetic oxygen production in the secondary cell at Long Beach. Since the oxygen production recorded at the 4-inch level (according to light-dark results) was inadequate to meet the respiratory demand at the lower levels, there must have been higher production actually taking place with circulation and turbulence to distribute this excess oxygen throughout the secondary cell in order to produce the results recorded in the 24-hour survey.

DISCUSSION

There are a number of studies on sewage stabilization ponds presently in progress or recently completed in this country and abroad where flexibility of design allows controlled experimentation. However, such was not the case at Long Beach; nevertheless, certain trends have been observed. When studied in the light of results from similar ponds, these trends stimulate many questions which appear to fall under the following headings: control of odors, single-celled versus multicell ponds; the place of secondary treatment by sewage



NET OXYGEN PRODUCTION AT THREE POND DEPTHS

FIGURE 8

ponds with conventional primary treatment versus complete treatment by sewage stabilization ponds, depth versus area, importance of turbulence and circulation as over against optimum depth for light penetration and photosynthesis, causes and control of animal plankters, and the like.

Berschauer (3) reported successful handling of loadings on the primary cell of the Redmond (Wash.) pond approaching 500 lbs. BOD/day where detention period was maintained in a range of 2-4 days. Often detention in the primary at Long Beach approached 8 days. Whitney's studies at Corvallis (16) were based on a single-cell pond receiving raw sewage. His results during the rainy season in Western Oregon indicated 80 per cent reduction in BOD with loadings of 30-50 pounds BOD per acre per day.

It appears that a primary cell is advantageous where space is limited in comparison with total loading. In comparison with 80 per cent reduction with 30-50 pounds loading at Corvallis, Long Beach showed over-all reductions as high as 96 per cent, with loadings 30-55 pounds BOD per acre per day.

In regard to raw sewage ponds versus ponds receiving primary effluents, both have their place. However, according to Neel (7):

> "It appears that raw sewage lagoons offer a type of algal environment that differs markedly in some respects from that of ponds receiving primary effluents. Raw sewage lagoons * * * are not preceded by any extensive periods of anaerobiasis and may lack amino acids and other compounds considered detrimental to algal growth (14). Introduction of raw sewage probably also provides larger and more constant quantities of algal nutrients."

This is consistent with Berschauer's findings, which are predicated upon fresh raw sewage and short detention times to avoid extended periods of anaerobiasis.

Oswald's (9) postulates regarding depth in relation to light penetration are apparently based on small cells or larger ones with dikes high enough to minimize wind action. Neel further states that effective utilization of light is not directly dependent upon lagoon depth, as circulation generally permits light contact with all water and suspended algae at intervals during daylight hours. This principle was earlier enunciated by Ruttner (13) who showed how the photosynthetic capacity of a lake is influenced by turbulent water movements and that in a mass of water thoroughly mixed by turbulence, all the phytoplankters enjoy the same average condition of light. Therefore, use of light-dark bottle tests for photosynthetic oxygen production and considerations of pond depth in relation to light penetration are valid only when circulation is at a minimum.

But the Pacific maritime climate is characterized by almost continuous air movement. Although turbulence was not measured directly at Long Beach, there was no temperature stratification and little O_2 stratification found at any time in the secondary cell. It is therefore concluded that circulation and turbulence exist and have been responsible for conditions as described by Rutter in lakes (Loc. Cit.).

Closely allied with consideration of depth and circulation are the relations of solar radiation to light utilization by phytoplankton in ponds and resulting oxygen production. In their studies of sewage ponds in South Dakota, Bartsch and Allum (2) show by calculation that the typical raw sewage pond produces as high as fifty times the amount of oxygen needed to satisfy the BOD of the influent sewage, but almost one-third of the total production is

required for algal respiration. Palmer (11) states that in cultures, algae may release twenty times as much oxygen by photosynthesis as they utilize in their metabolism. Marshall and Orr (6), however, in working with a maritime species of Euglenidae - Euglena proxima - in an isolated body of sea water off the coast of Scotland found that this organism utilized more oxygen for its respiration than it produced by photosynthesis. If this is true of other species of Euglena, perhaps herein lies the explanation, in part, for the low rates of O_2 production in winter at Long Beach when Euglenas were predominant.

Marshall also stated that animal plankters are inhibited by high pH which commonly occurs as a result of active photosynthesis. Values of pH over 9 were common at Long Beach in summer and fall, but dropped past neutral to the top of the acid range in winter and spring in the secondary cell at times when Daphnia swarmed and grazed the algae almost to extinction.

Despite lowered pH values in January and February (7.0-7.5) at the single-celled sewage pond in Corvallis, Oregon, Daphnia did not become a problem. Experience at Long Beach and as reported from other multiple-cell ponds and ponds receiving primary effluents indicates that periodic problems with Daphnia are to be expected in winter and early spring. A suggested measure for control is to bypass the primary units on a seasonal basis to assure the algae of a more steady supply of nutrients.

SUMMARY AND CONCLUSIONS

1. The sewage stabilization pond at Long Beach, Washington, was built in an effort to solve a difficult problem of waste disposal without positive assurance of success in the maritime climate of the Pacific Northwest.

2. Solar radiation at Long Beach in winter ranged 40-50% lower that at Fayette, Missouri, but only slightly lower than at Spokane, Washington. Records for spring and early summer indicated slightly lower solar radiation in Long Beach as compared with Fayette.

3. The continuous air movement and lack of temperature extremes in the maritime climate of Long Beach were conducive to maximum circulation in the ponds which, in turn, was favorable to photosynthesis throughout the 2-3 foot depth of pond.

4. The 2.5-acre multiple-cell pond receives an average daily loading in fall, winter and spring of 42 pounds BOD per acre day. In the summer the loading was 52 pounds per acre day. Reduction averaged 85 per cent during the winter and 82 per cent during the summer.

5. The ponds were found to be quite versatile in successfully accepting and effectively treating seasonal loads without upset.

6. Odors were of little consequence at any time, despite location within 100 yards of a dwelling.

7. Reduction in coliform bacteria ranged for the most part above 97 per cent.

8. Decreased solar radiation is perhaps the most important single factor in the virtual elimination of characteristic summer

and fall algal species: Micractinium pusillum and Scenedesmus sp., principally.

9. Other algae capable of surviving in conditions of low-level light, such as Euglena viridis and Chlorella spp. are largely responsible for photosynthetic activity in winter and spring.

10. Water fleas called Daphnia sp. swarmed twice in winter and early spring at Long Beach and grazed the algae almost to extinction. High pH of summer and fall with active photosynthesis is said to be unfavorable to growth of Daphnia. Natural control is possible by any method that will enhance algal growth in winter.

11. The advantages of a maritime climate such as at Long Beach in the operation of a sewage stabilization pond as expressed by narrow temperature range with enhancement of circulation and minimal, if any, ice cover, offset any disadvantage from lower level of solar radiation.

12. Consideration of the foregoing conclusions indicates that stabilization ponds can be expected to treat sewage effectively under the unusual climatic conditions of the Pacific Northwest.

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APPENDIX

TABLE XII
SEWAGE STABILIZATION POND- LONG BEACH, WASHINGTON
July 8 - 10, 1957

	Date and Time											
	July 8th										July 9th	
	0500	0700	0900	1100	1300	1500	1700	1900	2100	2300	0100	0300
Raw Sewage												
DO	2.7	1.75	1.1	0.0	0.0	1.05	2.7	0.5	1.4	0.7	.40	.80
pH	7.0	7.1	7.2	7.3	7.3	7.3	7.1	7.1	7.3	7.2	7.0	6.8
BOD	265		325		256		300		303		224	
MPNx10^3	110,000			4400			46000			46,000		
Temp. ^oC	15.	15.	16	16	16	16	16	16	16	16	16	15
Primaries												
DO	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	6.8	7.1	7.1	6.9	7.1	7.1	7.1	6.9	6.8	6.7	6.7	6.8
BOD	138		153		148		152		180		184	
MPNx10^3	11,000			360			11000			4,600		
Temp. ^oC	18.5	18.5	18	19.5	19.5	19.5	18	18	19	18.5	18	18
Secondary												
DO	8.45	11.2	16	14.95	15.0	14.75	15.8	11.8	10.6	8.9	6.7	4.8
pH	6.9	7.4	7.4	7.8	8.2	8.2	8.2	7.0	6.9	6.8	6.6	6.8
BOD	25		47		28		27		29		42	
MPNx10^3	150			2100			24000			4,600		
Temp. ^oC	20	20	21	21	21	20.5	20	19.	19.5	19	18.5	18.5

Table XII Continued

	Date and Time											
	July 9th										July 10th	
	0500	0700	0900	1100	1300	1500	1700	1900	2100	2300	0100	0300
Raw Sewage												
DO	0.0	0.2	0.1	0.3	0.0	0.25	1.15	0.8	0.7	0.0	0.3	0.2
pH	6.8	7.1	7.2	7.3	7.4	7.2	7.2	7.2	7.2	7.0	7.1	7.0
BOD	247		286		283		232		243		236	
MPNx10^3	11,000			24,000			110,000			4,600		
Temp.^{o}C	15.5	15.5	16.5	16.0	16.1	16.1	16.1	15.5	15.5	15.5	15	15
Primaries												
DO	0.0	0.0	0.0	1.0	0.0	0.9	1.40	0.0	0.0	0.0	0.0	0.0
pH	6.9	6.8	7.0	7.2	8.3	7.6	7.6	7.2	7.2	7.0	6.8	6.8
BOD	180		173		186		141		108		179	
MPNx10^3	11,000			4,600			24,000			4,600		
Temp.^{o}C	16.5	18.	20.5	23.	25.	26.	21.5	21.0	19.4	19.5	18.5	18.
Secondary												
DO	4.2	5.2	10.80	12.4	18.8	18.75	19.30	17.50	14.9	13.6	9.1	11.4
pH	6.7	6.6	8.2	8.6	8.9	9.6	9.6	9.6	8.4	8.0	7.1	7.1
BOD	30.		42.		35		35		133		34	
MPNx10^3	24,000			3,400			150			460		
Temp.^{o}C	17.	18.	19.5	21.1	23.5	24.5	24.5	22.	20.	20.	19.5	19.

TABLE XIII

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
September 4-5, 1957

	Time	DO	pH	BOD	MPNx10^3
Raw Sewage	0800	0.0	7.3	273	- - -
	1000	0.3	7.1	- -	- - -
	1200	0.0	6.9	324	- - -
	1400	0.0	7.3	- -	110,000
	1600	1.0	7.1	342	- - -
	1800	0.8	7.2	- -	- - -
	2000	0.65	7.1	296	110,000
	2200	0.0	7.0	- -	- - -
	1200	0.0	6.9	405	- - -
	0600	0.0	7.0	186	7,500
North Cell Anaerobic Lagoon	0800	0.0	6.9	124	- - -
	1000	0.0	6.9	- -	- - -
	1200	0.0	7.0	114	- - -
	1400	0.0	7.1	- -	11,000
	1600	0.0	7.1	108	- - -
	1800	0.0	7.1	- -	- - -
	2000	0.0	7.1	126	4,600
	2200	0.0	7.1	- -	- - -
	0200	0.0	6.9	130	- - - -
	0600	0.0	6.9	120	4,600
South Cell Anaerobic Lagoon	0800	0.0	7.1	153	- - -
	1000	0.0	7.1	- -	- - -
	1200	0.0	7.0	124	- - -
	1400	0.0	7.2	- -	4,600
	1600	0.0	7.1	111	- - -
	1800	0.0	7.2	- -	- - -
	2000	0.0	7.1	112	11,000
	2200	0.0	7.0	- -	- - -
	0200	0.0	7.1	95	- - -
	1600	0.0	6.9	105	11,000
Aerobic Cell	0800	2.5	8.0	32	- - -
	1000	9.3	8.1	- -	- - -
	1200	11.2	8.3	26	
	1400	19.4	8.8	- -	110,000
	1600	24.7	8.8	28	- - -
	1800	21.2	8.9	- -	- - -
	2000	25.00	9.2	26	210,000
	2200	17.4	8.8	- -	- - -
	0200	7.6	8.2	28	- - -
	0600	3.4	7.8	30	150,000

TABLE XIV

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
November 6-7, 1957

	Date - Time	DO	pH	BOD	MPNx10^3	Temp ^{o}C
Raw Sewage	Nov. 6 0900	--	7.6	---	24,000	13.0
	1500	--	7.3	---	15,000	14.0
	2100	--	7.0	---	11,000	- -
	Nov. 7 0300	--	- -	---	2,400	- -
	0600	--	7.0	280	Composite	- -
North Primary	Nov. 6 0900	--	7.4	---	- -	9.5
	1200	3.8	- -	---	- -	- -
	1500	2.8	- -	---	- -	11.7
	1800	0.0	6.9	---	- -	- -
	Nov. 7 0600					
South Primary	Nov. 6 0900	Trace	- -	---	7,500	9.5
	1500	1.8	7.8	---	4,600	11.7
	2100	0.0	6.9	---	24,000	- -
	Nov. 7 0300	0.0	- -	---	24,000	- -
	0600	--	- -	111	Composite - both cells	
Secondary	Nov. 6 0900	9.48	8.4	52.6	240	- -
	1200	16.0	- -	53.4	- -	- -
	1500	14.6	8.6	54.0	240	10.5
	1800	13.8	- -	53.8	- -	- -
	2100	12.2	7.6	54.6	460	- -
	2400	11.0	- -	54.0	- -	- -
	Nov. 7 0300	9.6	- -	53.8	24,000	- -
	0600	8.7	7.1	---	- -	- -

Flow: Gal/day -- 47,200

TABLE XV

SEWAGE STABILIZATION POND--LONG BEACH, WASHINGTON
December 11, 12, 13 and 14, 1957

		December 11						December 12	
		0900	1200	1500	1800	2100	2400	0300	0600
Raw Sewage	pH				6.9	6.9		7.2	7.1
	Temp °C	12							
North Primary	DO		0.0		0.0		0.0		0.0
	pH		6.6		6.6		6.8		6.9
South Primary	DO	0.0		0.0		0.0		0.0	
	pH	7.3				6.7		6.9	
Secondary	DO	3.1	5.3	7.3	6.6	5.3	4.5	3.7	2.8
	pH	7.2	7.2		6.8	6.9	6.9	6.9	6.9
	Temp °C	8.0							

Flow - Gal/day - 28,300

		December 12						December 13	
		0900	1200	1500	1800	2100	2400	0300	0600
Raw Sewage	BOD								350 Comp.
	MPNx10^3		9300		240,000		46,000		24,000
	Temp °C	11.5							
North Primary	DO		0.0		0.0		0.0		0.0
	MPNx10^3		11,000		24,000		4,600		24,000
	Temp. °C	9.2							
South Primary	DO	0.0		0.0		0.0		0.0	
	BOD								116
	Temp. °C	9.2							
Secondary	DO	2.4	6.6	7.2	6.1	5.6	4.8	4.5	3.5
	BOD								31
	MPNx10^3		240		460		240		240
	Temp. °C	9.0							

Flow - Gal/day - 30,000

See separate table - Special DO Samples from Secondary Cell

TABLE XV (Continued)

		December 13						December 14	
		0900	1200	1500	1800	2100	2400	0300	0600
Raw Sewage	pH		8.1			6.8			6.8
	Temp. oC	10.5	12.0	10.5		10.0	10.0	9.8	9.0
North Primary	DO	0.0		0.0		0.0		0.0	
	pH			6.9		6.4		6.6	
	Temp. oC	8.0		10.0		10.0			
South Primary	DO		0.1		0.0		0.0		0.0
	pH		6.8		7.0		6.4		7.0
	Temp. oC		10.0		10.0		10.0		
Secondary	DO	0.1	0.4	0.4	.8	0.4	0.7	0.8	0.8
	pH		6.8	6.7	7.0	6.8	7.2	6.4	6.8
	Temp. oC	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Flow - Gal/day - 35,000

TABLE XVI

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
February 4-5, 1958

		February 4						February 5	
		0900	1200	1500	1800	2100	2400*	0300	0600
Raw Sewage	pH	--	8.1	7.0	--	6.8	--	--	6.8
	BOD								311 Comp.
	MPNx10^3		24,000		4,300	--	240,000		9,300
	Temp. °C	10.5	11.5	10	11	10	10		9.0
North Primary	DO	--	0.1	--	0.0	0.0	--	0.0	--
	pH	--	6.8	--	7.0	6.4	--	6.6	--
	BOD								79
	MPNx10^3		24,000						
	Temp. °C	--	10	--		10	--	9.0	--
South Primary	DO	0.0		0.0		--	0.0		0.0
	pH			6.9			6.4		7.0
	MPNx10^3	--			4,600		2,100		4,600
	Temp. °C	9.0							
Secondary	DO	0.1	0.4	0.4	0.8	0.4	0.7	0.8	0.8
	pH	---	6.8	6.7	7.0	6.8	7.2	6.4	6.8
	BOD	--			--				12
	MPNx10^3		240		460		150		1,100
	Temp. °C	8.0	10	10	10	10	10	9.0	10

Flow in Gal./day - 60,000

* Heavy Rain at 0115

TABLE XVII

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
March 6, 1958

	0700	0900	1100	1300	1500	1700	1750	1900
Raw Sewage								
pH	7.1	7.2	7.7	7.7	7.6	7.7		7.5
BOD								270 Comp.
Temp. °C		9.0	10.	10.	10.	10.		10
North Primary								
DO	0.0							
pH	7.0							
BOD	98							103
Temp. °C	7.0							
South Primary								
DO	0.0							
pH	7.0							
BOD	131							127
Temp. °C	7.5							
Secondary								
DO	11.9	13.3	14.8	15.8			13.9	
pH	7.0	8.7	8.7	8.7			8.8	
BOD	30							42
Temp. °C	7.0		8.5				9.5	

Flow - Gal./Day - 47,200

Weather - Light rain in early afternoon

TABLE XVIII

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
March 26, 1958

	Time						
	0700	0900	1100	1300	1500	1700	1900
Raw Sewage							
pH	7.2	7.0	7.6	7.4	7.2	6.4	
BOD							254 Comp
Temp. °C	10.	10.	11.	11.	11.0	11.0	11.
North Primary							
CO	0.2	6.0	5.2	8.8	13.8	12.2	10.9
pH	7.2	7.4	7.4	7.7			
BOD	88.3						79.8
Temp. °C	10.	10.	10.	10.	10.	10.	10.
South Primary							
DO	0.0	0.5	4.7	11.0	12.6	8.8	4.8
pH	7.2	7.4	7.4	7.8			
BOD	111.						115.
Temp. °C	10.	10.	10.	10.	10.	10.	10.
Secondary							
DO	1.4	4.5	4.7	10.	12.7	10.5	12.
pH	6.8	7.2	7.2	7.4	7.2		
BOD	22.4						31.8
Temp. °C	10.	10.	10.	10.0	10	10	10

Weather - Sunny - 10 mph N.W. wind - Heavy algal bloom

Flow - Gal/day - 47,200

Spot Checks for DO

1600 - 3/26

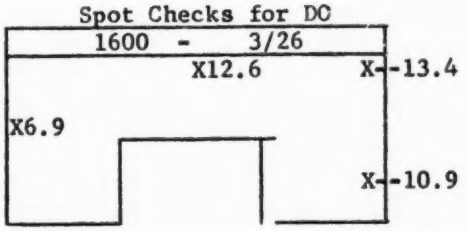

TABLE XIX

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
April 2, 1958

	Time		
	1100	1300	1500
North Primary			
DO	1.5	4.5	4.35
pH	7.0	7.4	7.4
Temp oC	9.5	10.0	10.5
South Primary			
DO	0.0	0.0	0.05
pH	7.1	7.1	7.2
Temp oC	9.5	10.0	10.5
Secondary			
DO	12.1	14.1	15.85
pH	8.4	8.4	8.7
Temp oC	9.5	9.5	10.5

Weather and other notes: Stormy, squally, rainshowers with intermittent sunshine. South wind up to 40-50 m.p.h. Good bloom developed in secondary cell

Flow - Gal/day - 66,000 Special samples at 1530

DO-16.7 pH 8.8 --x

x DO-15.5 pH- 8.6

DO-16.1 pH- 8.7 x

TABLE XX

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
April 15, 1958

	Time						
	0700	0900	1100	1300	1500	1700	1900
Raw Sewage							
pH	7.1	7.6	7.5	7.3	7.2	7.2	7.3
BOD							186 Comp.
Temp °C	10.	10.5	10.5	10.5	10.5	10.5	10.5
North Primary							
DO	0.0	0.3	1.2	0.0	2.7	1.1	1.0
pH	7.1	7.0	7.2	7.1	7.2	7.2	7.0
BOD		78					77
Temp °C	10.	11.0	10.5	11.0	11.0	11.0	11.5
South Primary							
DO	0.0	0.0	0.0	1.9	0.0	0.0	0.0
pH	7.0	7.0	7.0	7.1	7.0	7.1	7.1
BOD		115x0					132
Temp °C	10.	11.0	10.5	11.0	11.5	11.0	11.0
Secondary							
DO	6.4	7.0	10.0	11.0	11.6	12.	11.2
pH	7.8	7.8	8.4	8.7	8.7	8.8	8.7
BOD		41					40
Temp °C	11.	10.5	11.0	11.5	11.5	11.	10.5

Weather and other notes: Strong west wind; 25-30 MPH - A few showers
Flow - Gal/day - 61,300
See Special DO Samples from Secondary Cell - separate table.

TABLE XXI

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
May 14, 1958

	Time						
	0700	0900	1100	1300	1500	1700	1900
Raw Sewage							
pH	7.2	7.8	7.8	7.6	7.6	7.8	
BOD							245 Comp.
Temp oC	13.1	13.3	15.	15.6	15.6	15.6	
North Primary							
DO	0.5	9.0	18.	15.5	13.5	7.5	
pH	7.4	7.6	7.4	7.4	7.8	7.4	
BOD	99	—	—	—	—	112	
Temp oC	16.1	16.7	16.7	17.2	21.7	17.4	
South Primary							
DO	0.0	8.9	15.6	16.7	10.3	9.7	
pH	7.2	7.4	7.4	7.4	7.6	--	
BOD	133	—	—	—	—	>183	
Temp oC	16.1	16.7	17.2	17.8	19.4	17.8	
Secondary							
DO	0.4	1.8	4.3	5.5	5.1	7.7	
pH	7.2	7.2	7.2	7.2	7.2	7.2	
BOD	>88	—	—	—	—	65	
Temp oC	16.1	16.1	16.7	17.2	18.9	17.2	

Flow: Gal/day - 47,000

TABLE XXII

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
May 21, 1958

	Time			
	0800	1000	1100	1200
North Primary				
DO	0.0	2.8	4.5	
pH	7.1	7.1	7.8	
Temp. oC	16.0	17.2	19.0	
South Primary				
DO	0.0	1.2	6.7	
pH	7.1	7.2	7.7	
Temp. oC	16.			19.5
Secondary				
DO	7.5	11.0	15.6	13.6
pH	8.0	7.8	8.6	8.6
Temp. oC	18	18	19.5	19.5

Flow: Gal/day - 47,000

TABLE XXIII

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
June 2, 1958

	Time						
	0700	0900	1100	1300	1500	1700	1900
Raw Sewage							
pH	7.8	8.0	7.5	7.3	7.2	7.2	7.0
BOD							276 Comp.
Temp. °C	15.	14.4	15.0	15.0	15.0	15.0	15.0
North Primary							
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	7.2	7.0	7.2	7.4	7.3	7.2	7.2
BOD	101						109
Temp. °C	17.2	17.2	17.2	17.2	17.2	17.2	17.2
South Primary							
DO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	7.1	7.0	7.1	7.0	7.2	7.2	7.2
BOD	84.5						124.9
Temp. °C	17.2	17.2	17.2	17.2	17.8	17.5	17.2
Secondary							
DO	1.4	0.4	3.2	4.8	5.9	9.3	9.0
pH	7.5	7.4	7.6	7.6	7.8	8.4	7.8
BOD	90.6						81.0
Temp. °C	18.3	18.3	18.3	18.3	18.9	19.4	18.5

Flow: Gal/day - 56,600

TABLE XXIV

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON
June 24-25, 1958

	Date and Time									
	June 24			June 25						
	1100	1400	1600	0700	0900	1100	1300	1530	1730	1900
Raw Sewage										
pH				7.5		7.8	7.3	7.4		7.5
BOD										247 Comp.
MPNx10^3				24,000			46,000	46,000		
Temp. ^{oC}						16.5	16.	16.	16.	16.
North Primary										
DO	0.8	6.1	6.7	0.0	0.2	2.1	6.2	8.7	7.6	5.2
pH	6.9	7.0	7.3	7.3	7.1	7.4	7.5	7.6	7.5	7.3
BOD						74.			74.	
MPNx10^3				11,000			930	24,000		
Temp. ^{oC}	18.5	18.5	19.0	17.5	18.		19.5	20.5	20.0	
South Primary										
DO	0.0	0.0	0.0	0.0	0.6	4.0	10.1	11.9	9.3	6.6
pH	6.9	7.0	7.1	7.1	7.1	7.5	7.5	7.7	7.6	7.4
BOD						68.			72.	
MPNx10^3				2,400			4,600	24,000		
Temp. ^{oC}	19.0	19.0	19.0	18.0	18.		21.	21.5	21.	
Secondary										
DO	0.0-1.1	1.2-4.2	3.4-8.3							
pH	7.2	7.3	7.7-	0.1	0.00	4.0	8.1	14.8	13.3	--*
BOD				7.3	7.3	7.5	7.7	8.3	8.4	7.7
MPNx10^3				2,100		60.	460	1,100	45.	
Temp. ^{oC}	18.5	19.	20.0	18.0	18.0	--	--	20.5	20.5	

Flow: Gal/day - 54,000

* See separate table, Special DO Samples from Secondary Cell - 1900 - June 25, 1958.

SPECIAL DO SAMPLES FROM SECONDARY CELL

SEWAGE STABILIZATION POND - LONG BEACH, WASHINGTON

Time and Date	Location	DO in ppm		
		Near Surface	Mid-Depth	Near Bottom
Around noon 12/13/57	Northwest corner	4.5	4.6	4.6
	Northeast corner	4.9	4.9	4.7
	Southeast corner	3.2	2.1	1.5
	Southwest corner	5.7	4.9	5.1
1630-1730 4/15/58	Northwest corner	10.9	10.6	10.4
	Northeast corner	12.2	12.1	11.7
	Southeast corner	11.6	10.5	10.3
	Southwest corner	10.4	10.0	9.6
		Surface		
1900 6/25/58	Northwest corner	1.9	0.0	0.0
	Northeast corner	10.4	4.2	0.1
	Southeast corner	14.2	14.2	13.8
	Southwest corner	15.2	14.7	14.9